Spin-wave nanograting coupler

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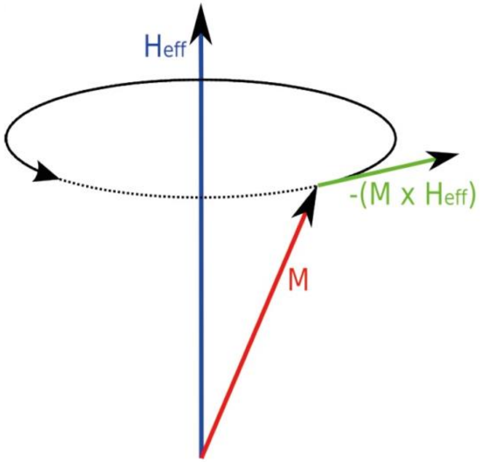
Outline

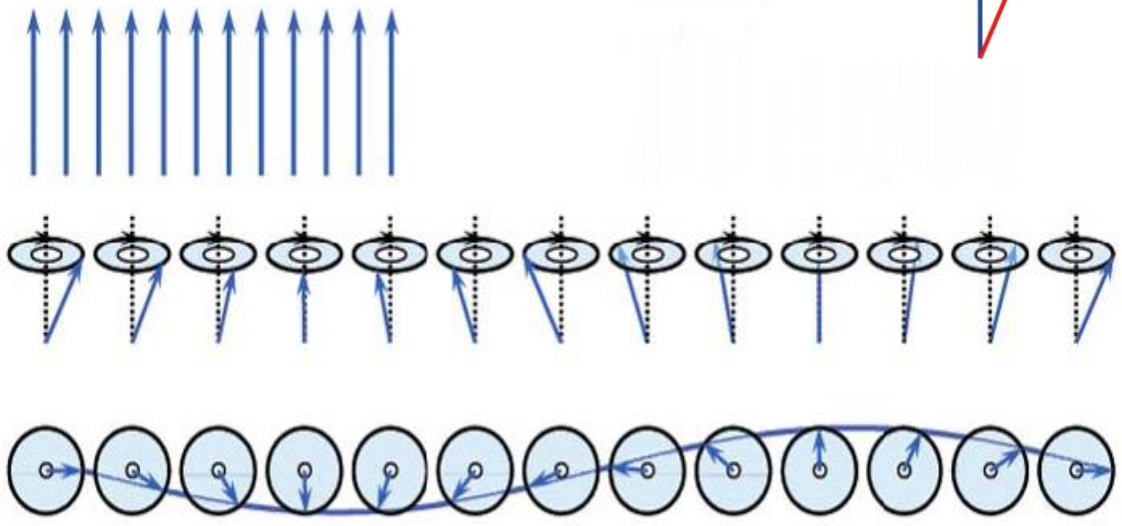
1. Fundamentals on Spin Waves
2. Spin Waves nano-grating coupler
3. Sample Preparation
4. Further Analysis and conclusion

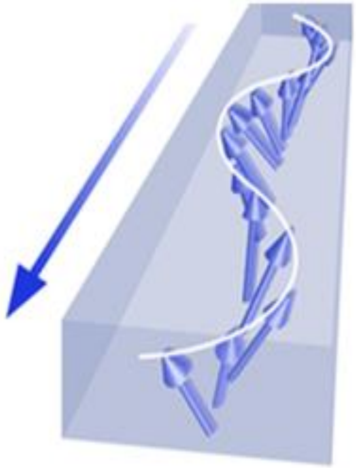
1.Fundamentals on Spin Waves

What is a spin wave?

- Aligned spins
- Starts to precess
- Couple to their neighbours







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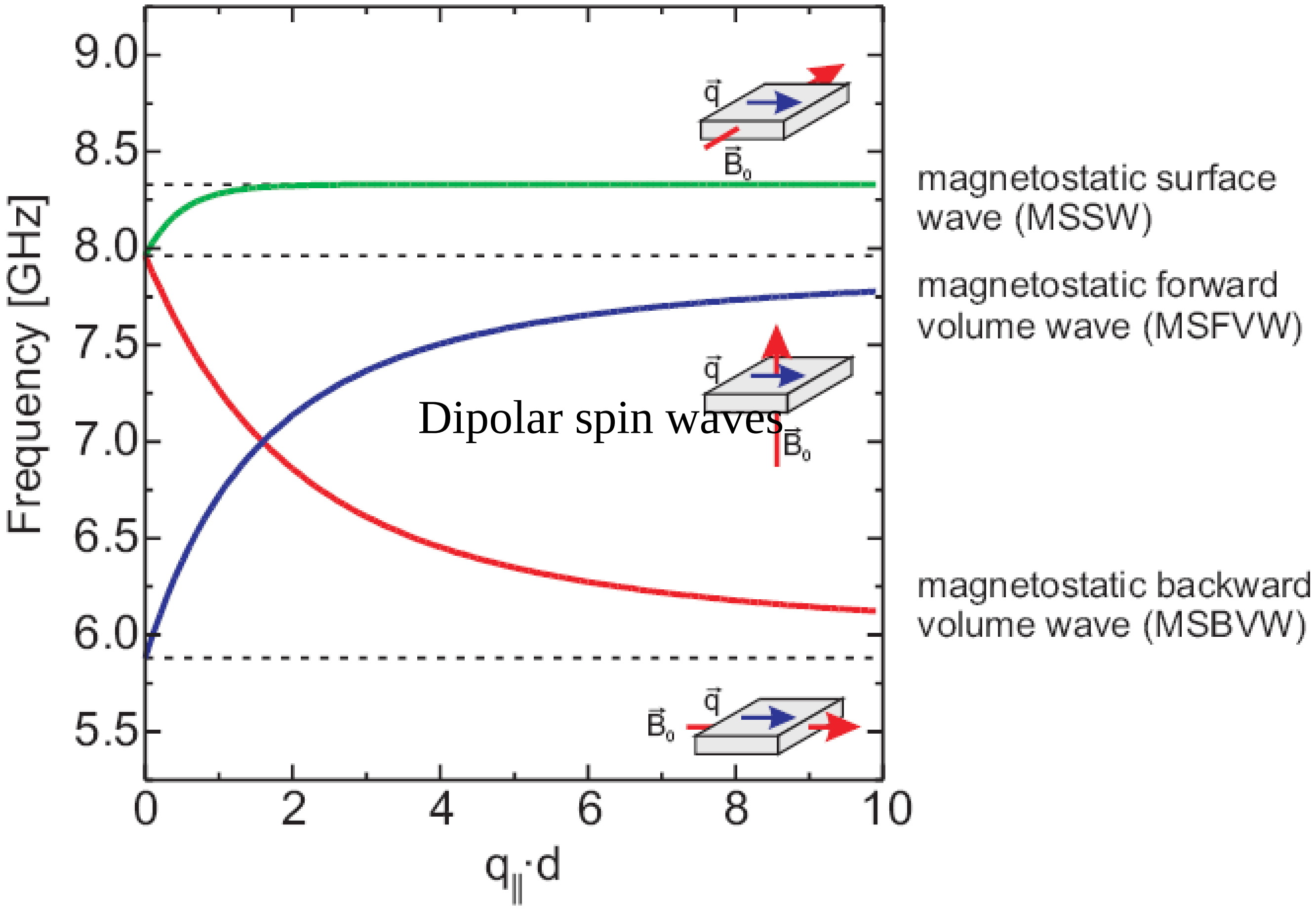
Dipolar spin waves dispersion



Dipolar spin waves

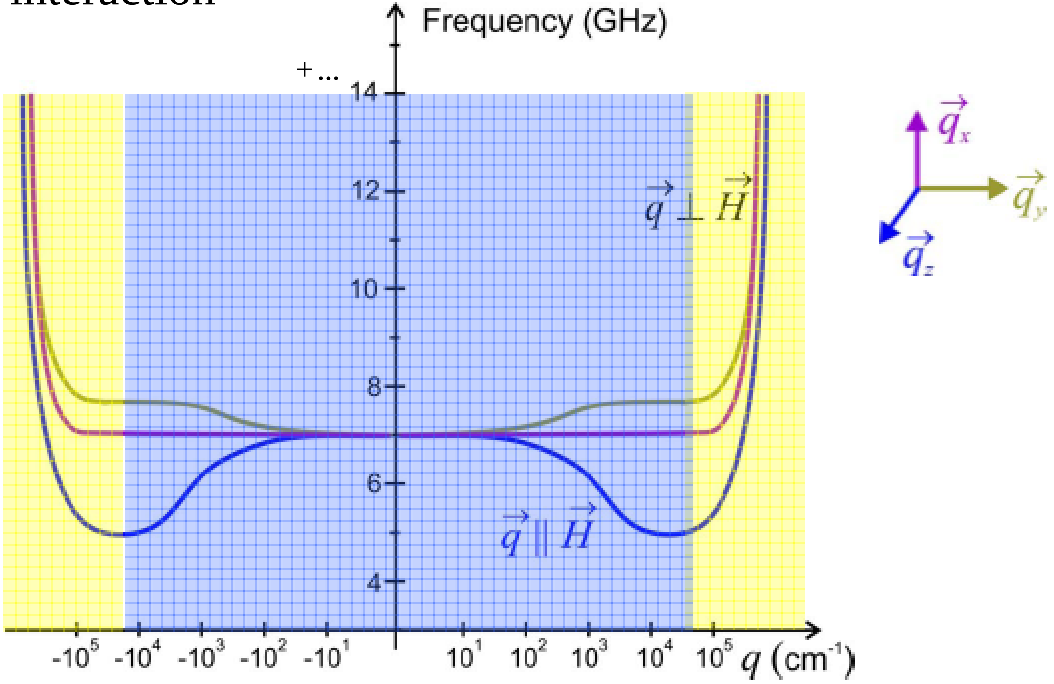
Spin waves - dipolar-exchange

Landau-Lifshitz equation: $$\frac{\partial \vec{M}}{\partial t} = -|\gamma| \vec{M} \times \vec{H}_{eff}$$

$$\vec{H}_{eff}(\vec{r}) = \vec{H}_{appl} + \boxed{\int_V \tilde{G}(\vec{r}, \vec{r}`) dr`^3} + \boxed{\frac{2A}{M_s^2} \nabla^2 \vec{M}} + \dots$$

dipolar interaction

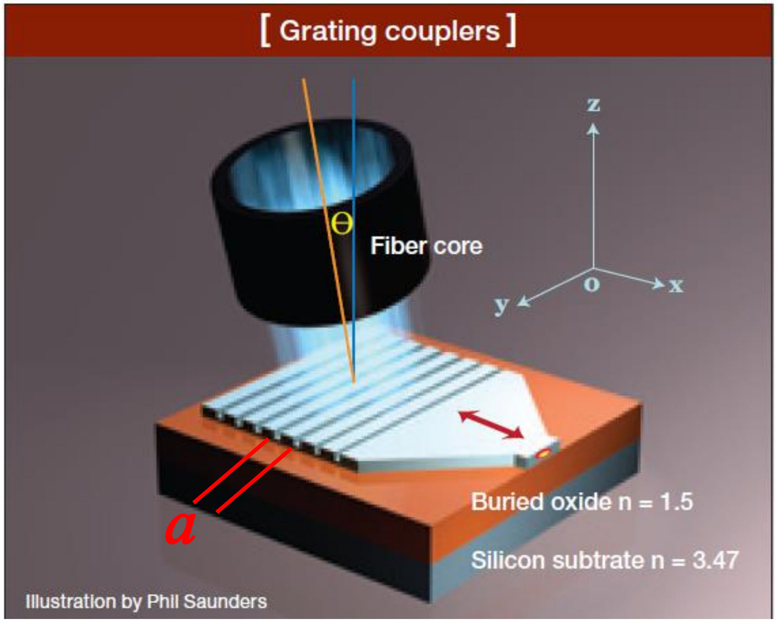
exchange interaction



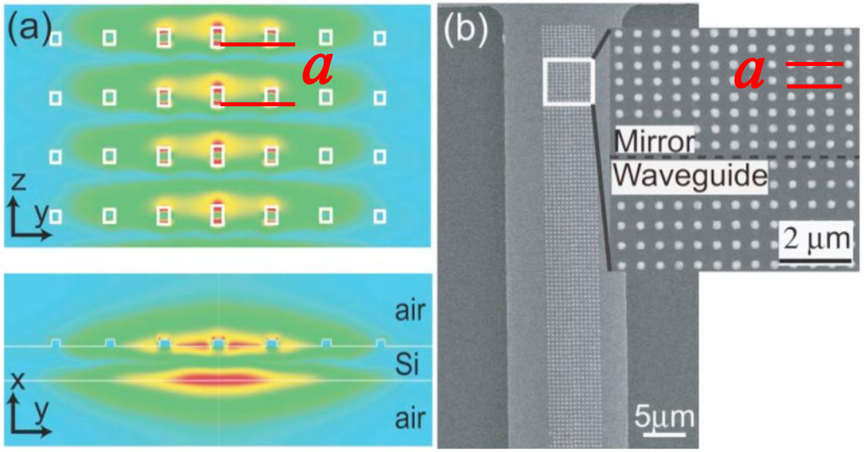
2. Spin Waves nano-grating coupler

Grating Coupler Effect in Plasmonics and Photonics

The grating coupler vector is defined as $G = 2\pi/a$, where a is the period of the grating.

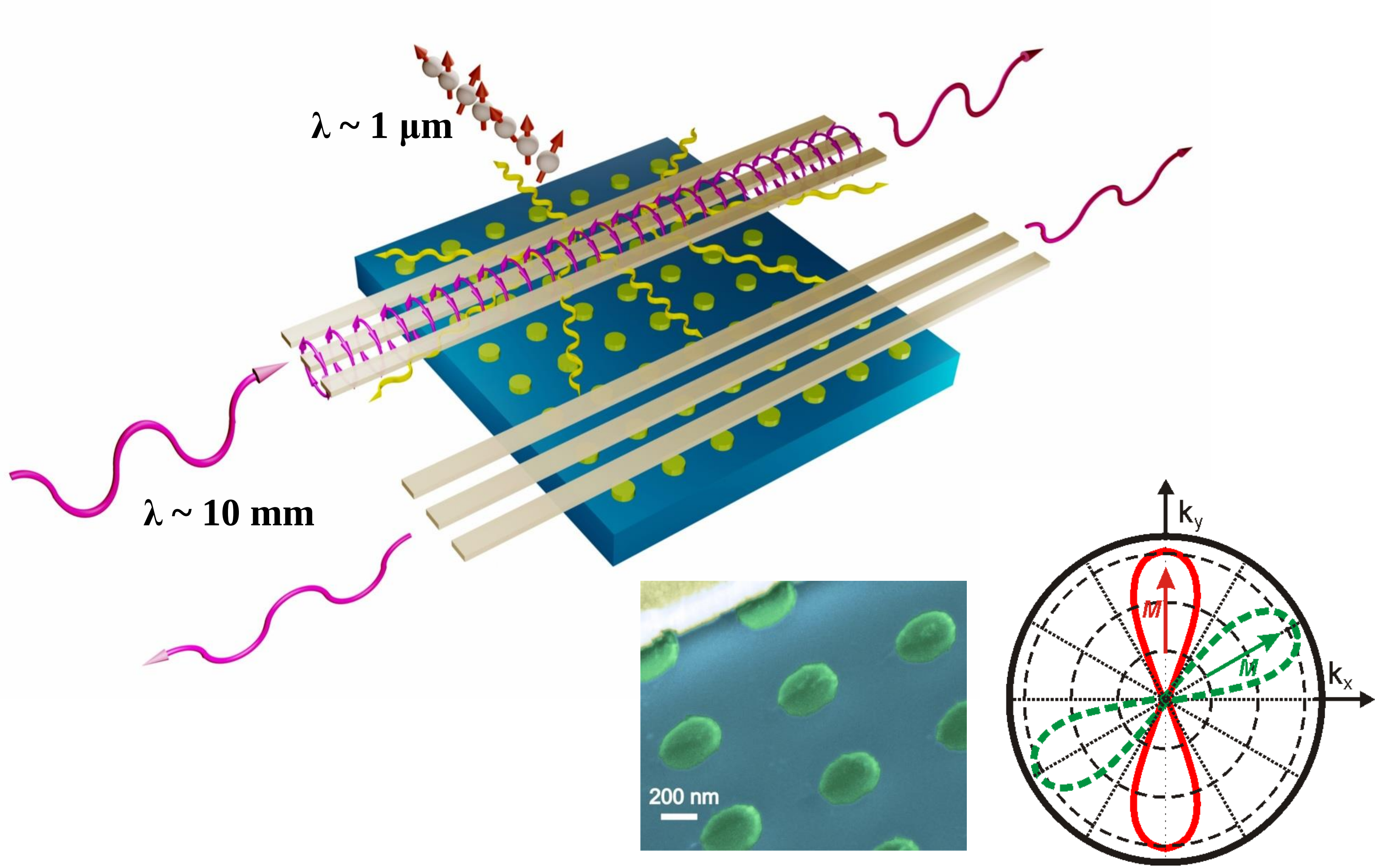


X. Chen et al. *Opt. Lett.* 36, 796 (2011).

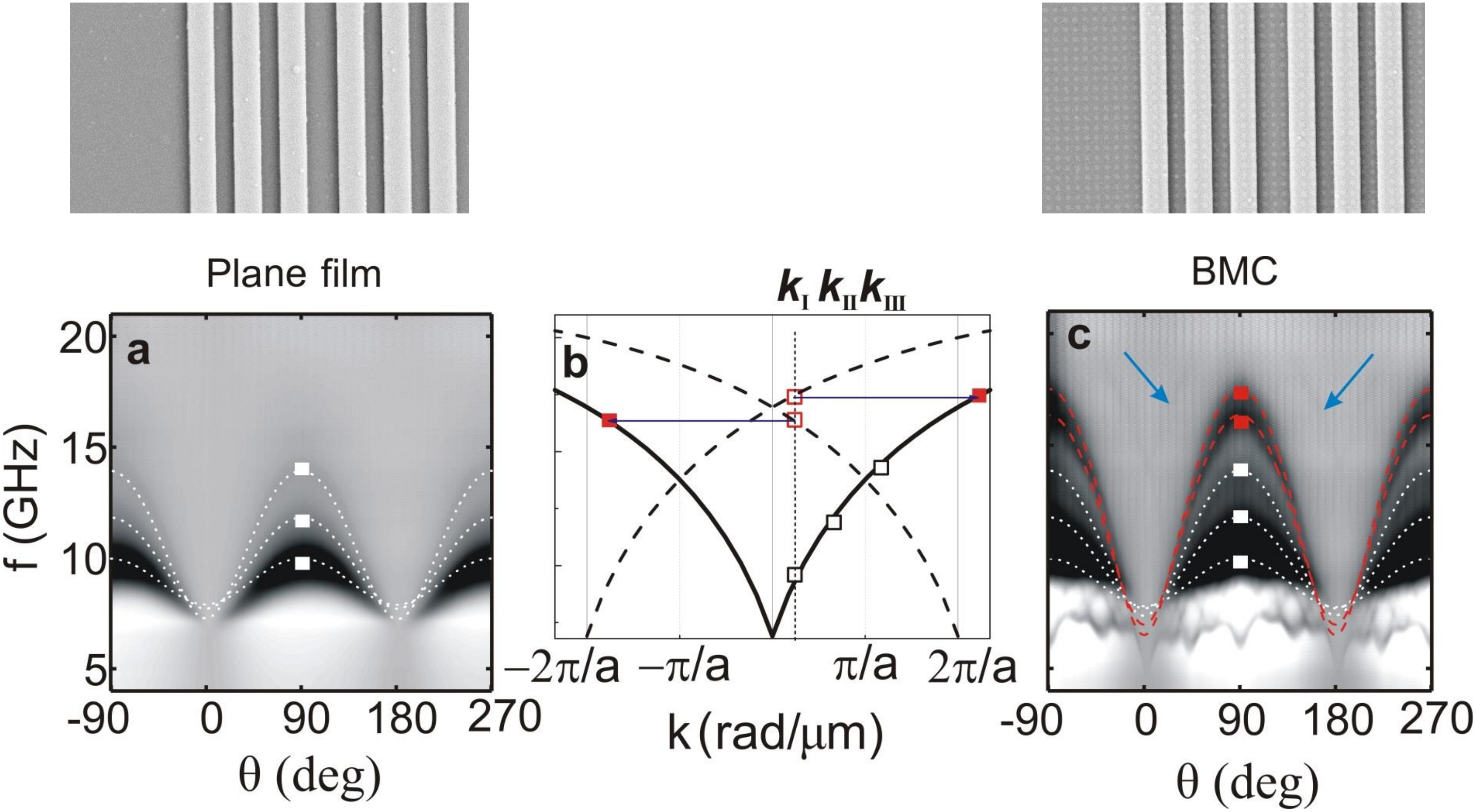


Ekmel Ozbay, Plasmonics: Merging Photonics and Electronics at Nanoscale *Science* **311**, 189 (2006);

Magnonic Grating Coupler



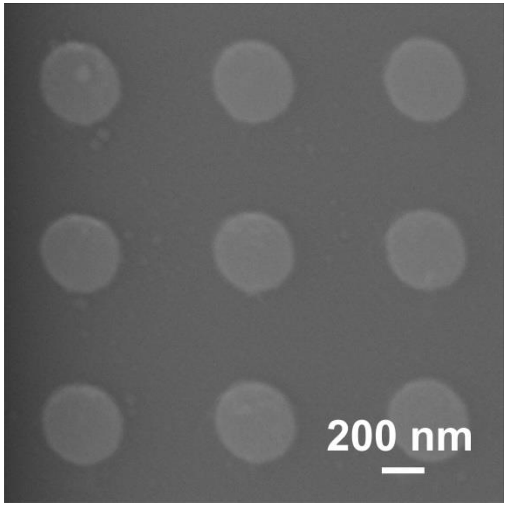
Key Results

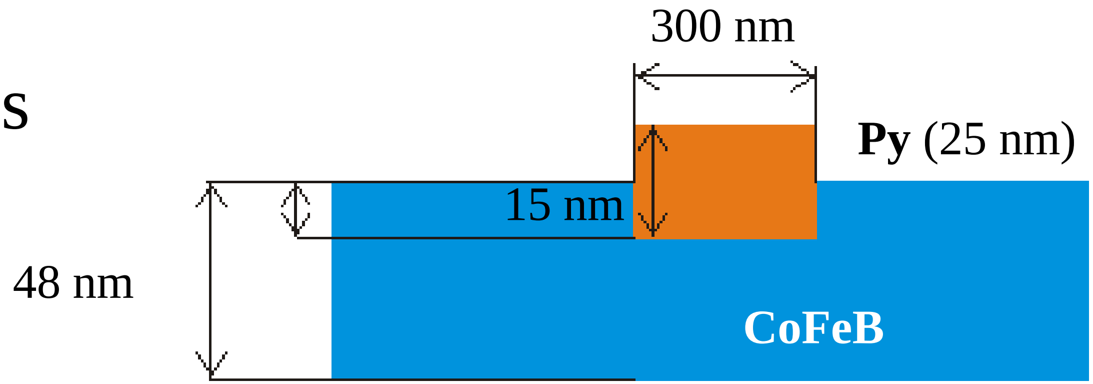

Plane film
BMC
a
b
c
k_{I} k_{II} k_{III}
f (GHz)
20
15
10
5
-90
0
90
180
270
θ (deg)
−2π/a
−π/a
π/a
2π/a
k (rad/μm)

3. Sample Preparation

Dot Structure

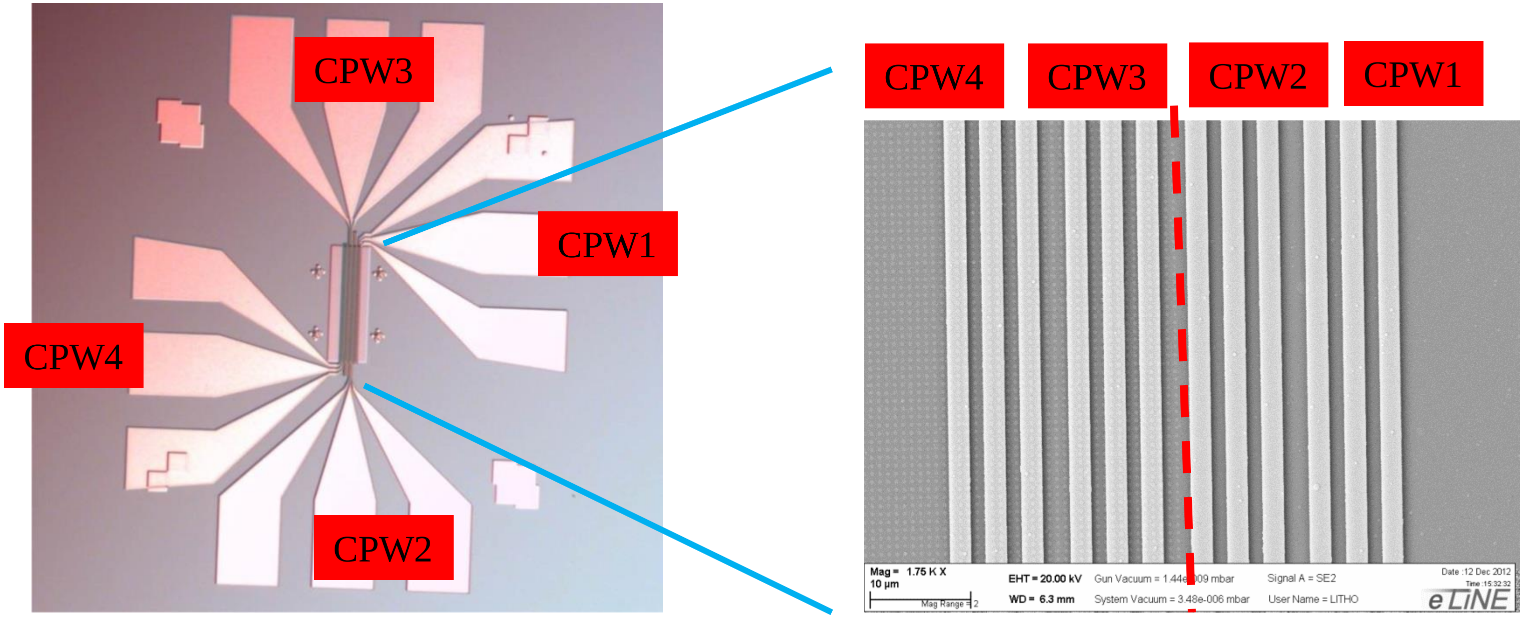
1. E-beam lithography
2. Ion beam milling
3. Evaporation of Py or Co
   (without taking it from the vacuum chamber!)
4. Lift-off process





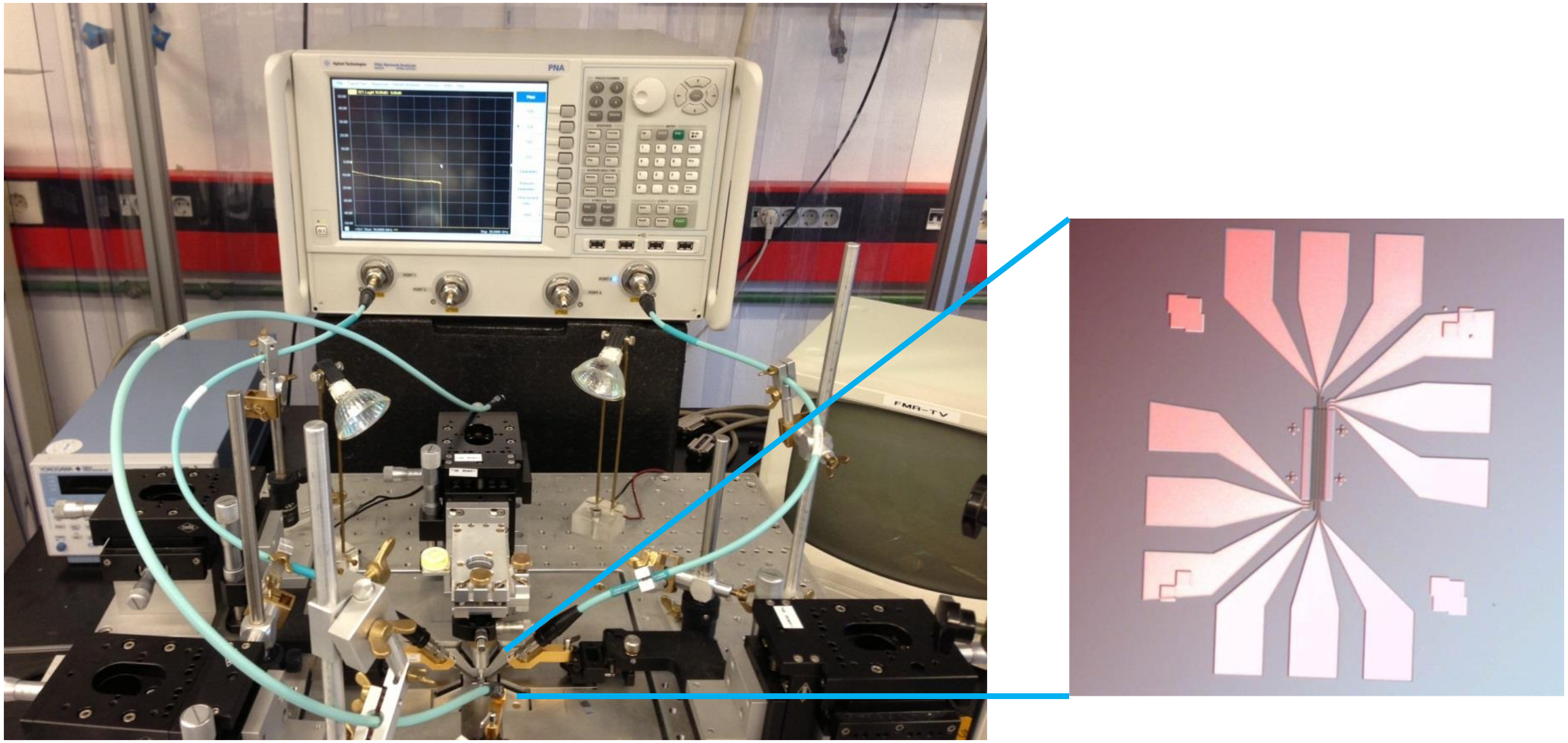
Integrate Spin Wave Antennae Coplanar Waveguide (CPW)

1. Al_2O_3 (5 nm) using Atomic Layer Deposition
2. E-beam Lithography for 4 Integrated Gold CPWs



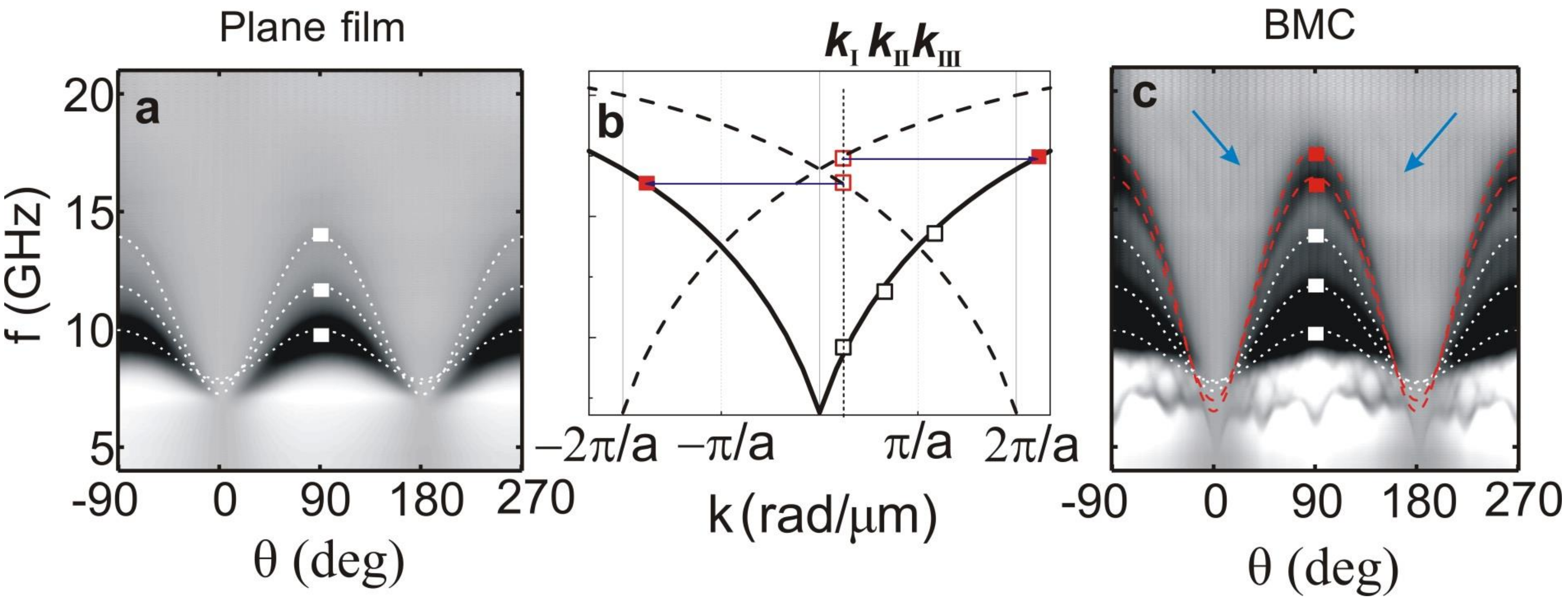
3. Spin-wave Measurements

VNA Setup

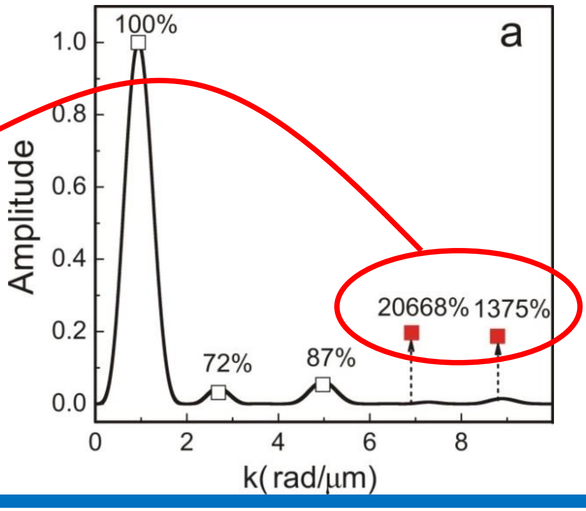


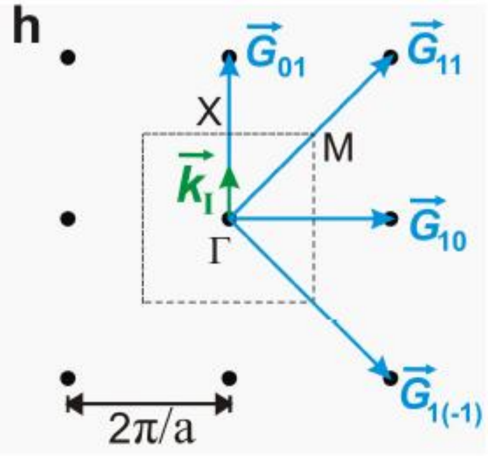
The microwave current supplied by the VNA excites the spins through the oscillating magnetic field which surrounds the inner conductor

Angle Dependence @ 40mT



$$k_{\mathrm{I}} \pm G_{01}$$





Spin-wave Modes Simulation

Daemon-Eshbach mode dispersion

$$\omega_{DE}^2 = \omega_H(\omega_H + \omega_M) + \frac{\omega_M^2}{2}(1 - e^{-2kd})$$

Backward Volume mode dispersion

$$\omega_{BV}^2 = \omega_H\left[\omega_H + \omega_M\left(\frac{1 - e^{-2kd}}{kd}\right)\right]$$

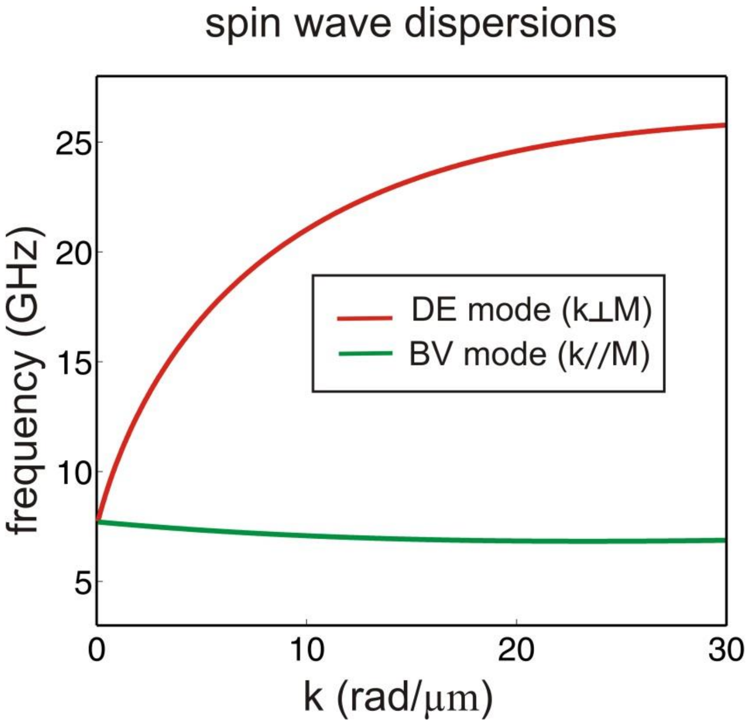
$$\omega_H = \gamma\mu_0 H$$

$$\omega_M = \gamma\mu_0 M_s$$

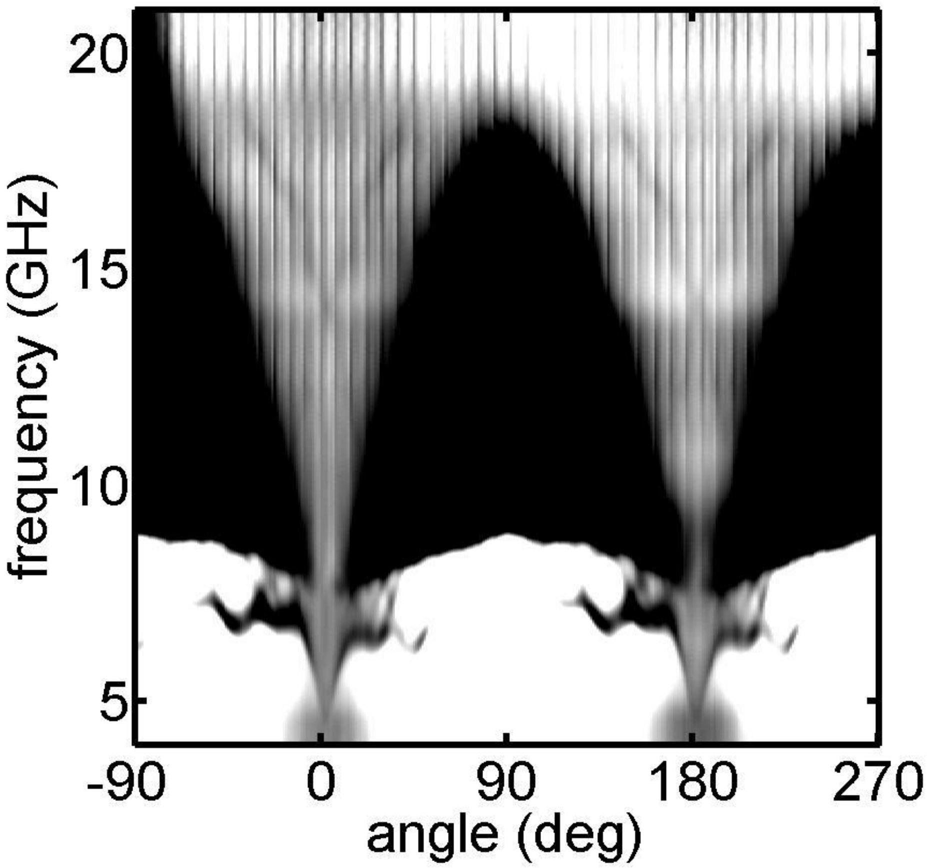
$d = 48$ nm

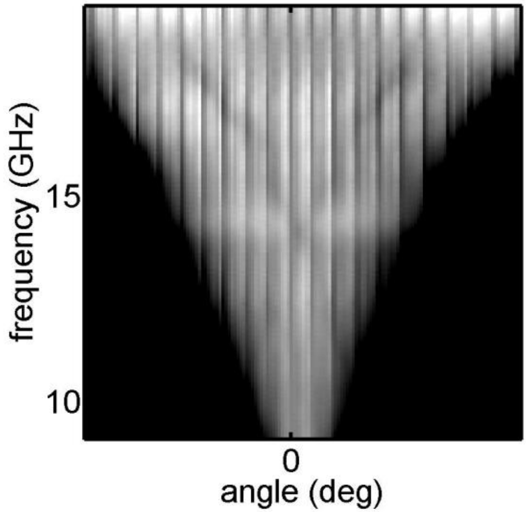
$\mu_0 M_s = 1.8$ T

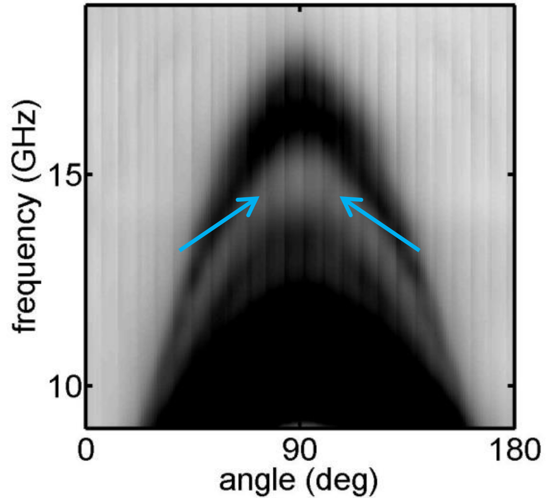
$\mu_0 H = 40$ mT



“Crossing” modes

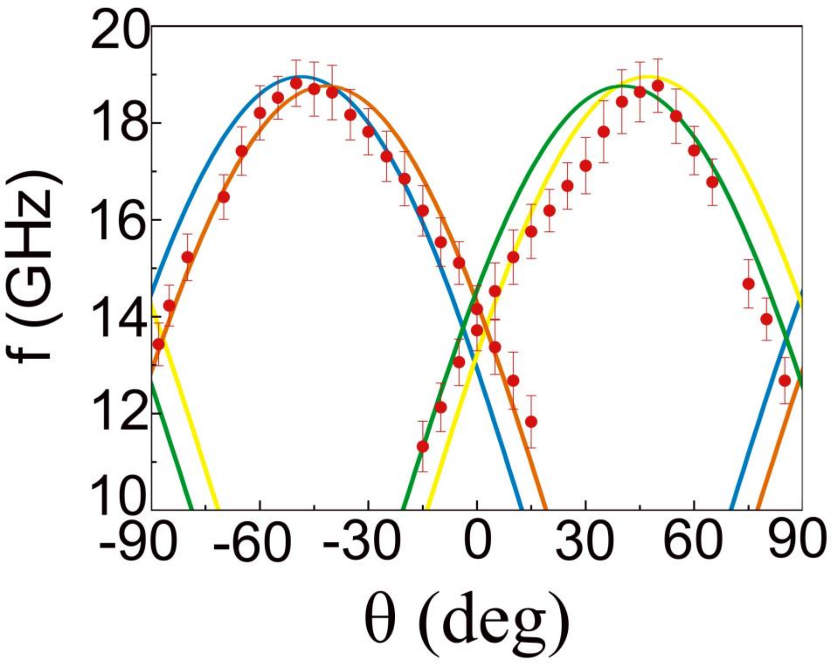


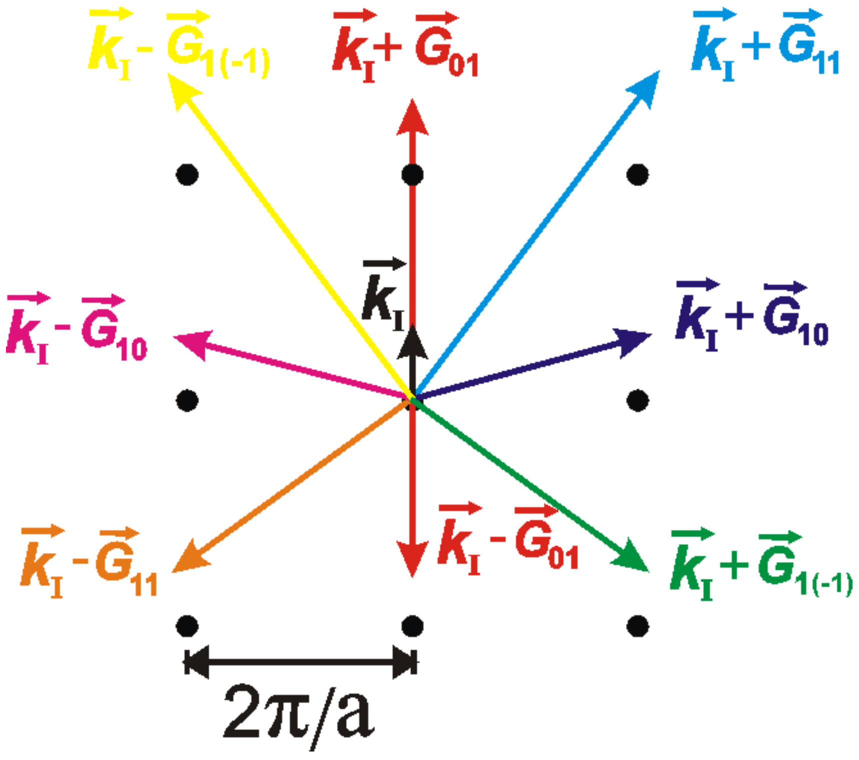




Omnidirectional Spin Wave Modes

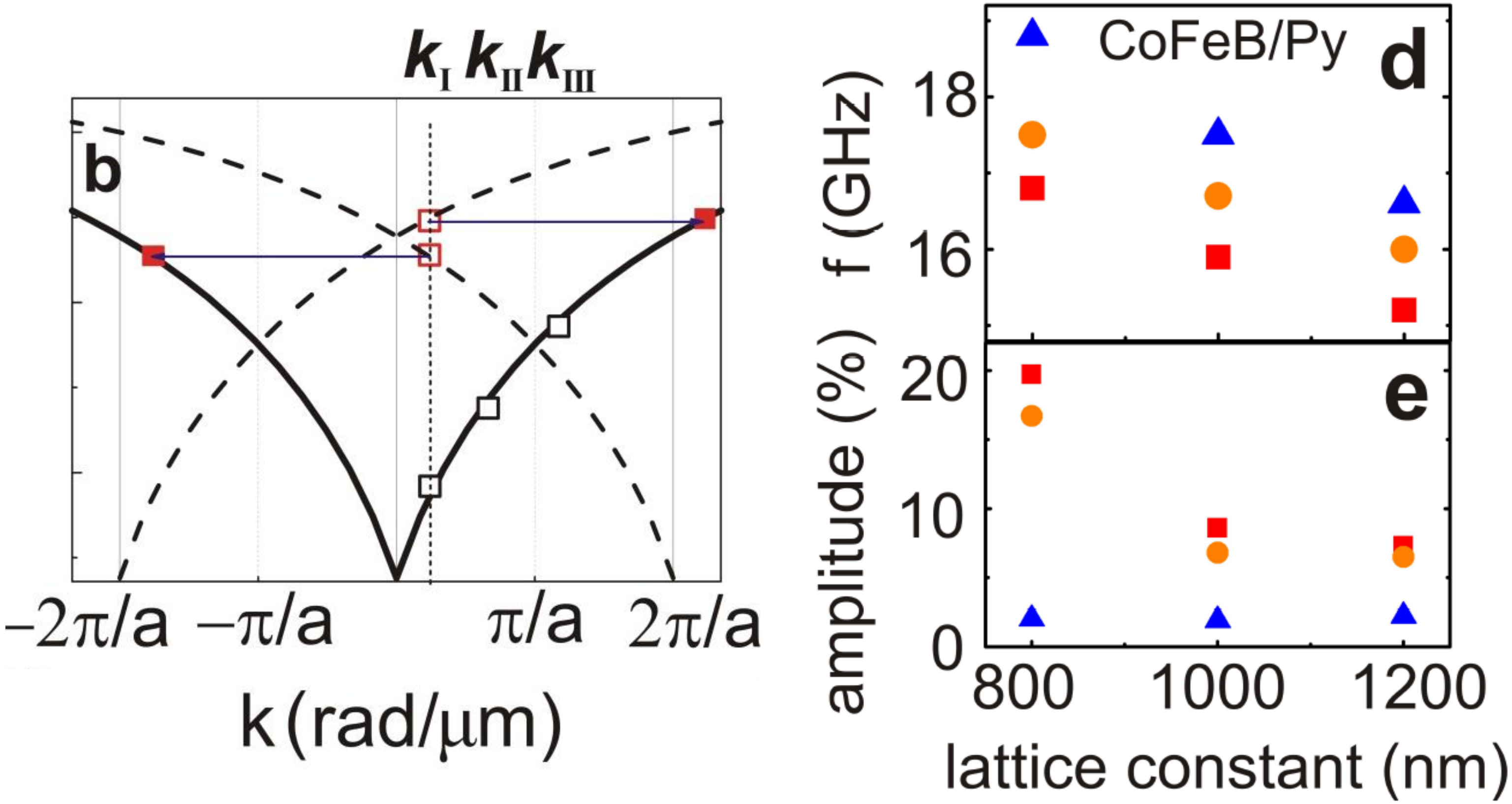
$$\vec{k}_\mathrm{I}+\vec{G}_{11} \quad \vec{k}_\mathrm{I}-\vec{G}_{11} \quad \vec{k}_\mathrm{I}+\vec{G}_{1(-1)} \quad \vec{k}_\mathrm{I}-\vec{G}_{1(-1)}$$





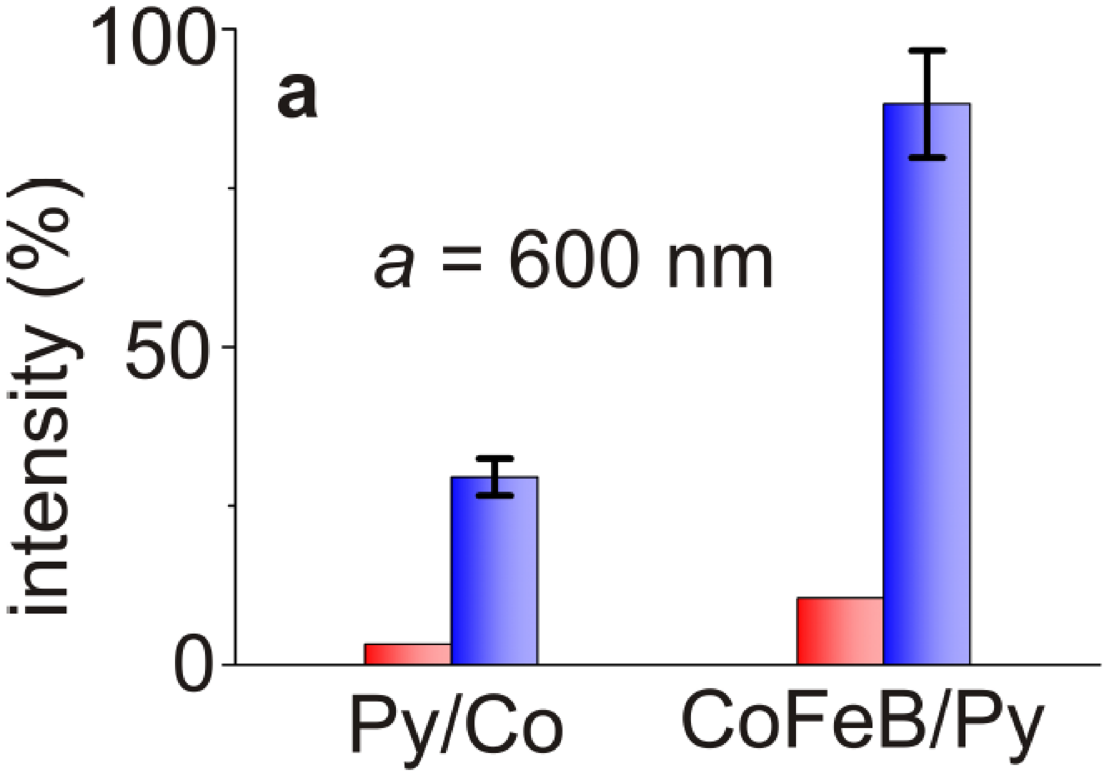
4. Further Analysis

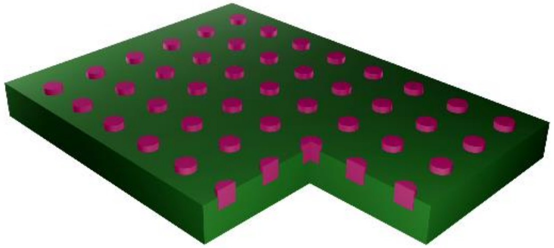
Lattice Constant Dependence

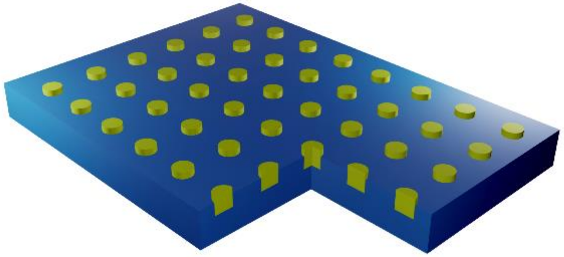


(e) Signal strengths of modes with $\vec{k}_{\mathrm{I}} - \vec{G}_{01}$ (squares), $\vec{k}_{\mathrm{I}} + \vec{G}_{01}$ (circles) and $\vec{k}_{\mathrm{I}} + \vec{G}_{11}$ (triangles) measured on the CoFeB/Py BMCs with different lattice constants a. Signal strengths are normalized to the k_{I} signal.

Material Dependence







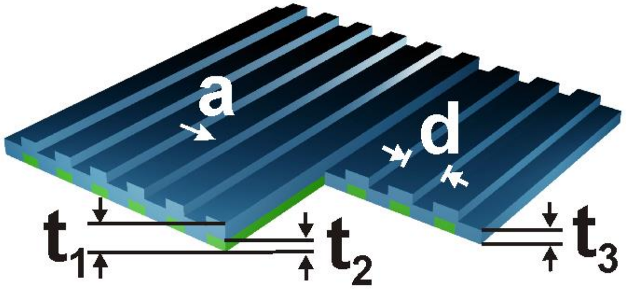
5. Conclusion

Advantages and perspectives

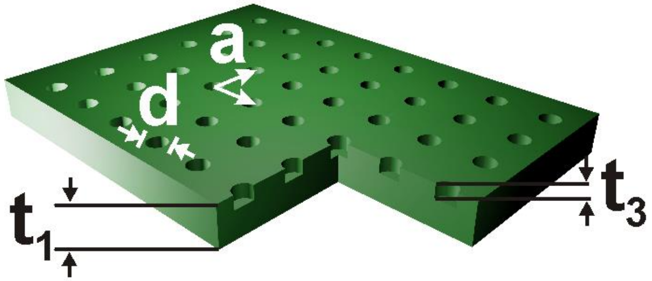
1. Omnidirectional spin wave emission
2. Wave vector tuned by lattice constant
3. Engineered BMC by changing two materials for even larger spin wave enhancement
4. Interlock the phase of neighboring spin transfer torque nanooscillators

Thank you for your attention!

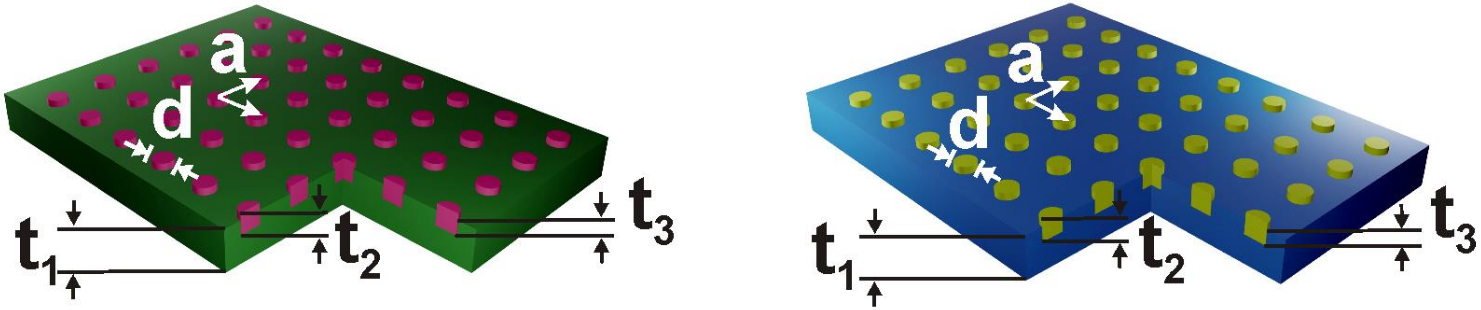
Magnonic Crystals (MCs)



1D MC



Anti-Dot Lattices (ADLs)

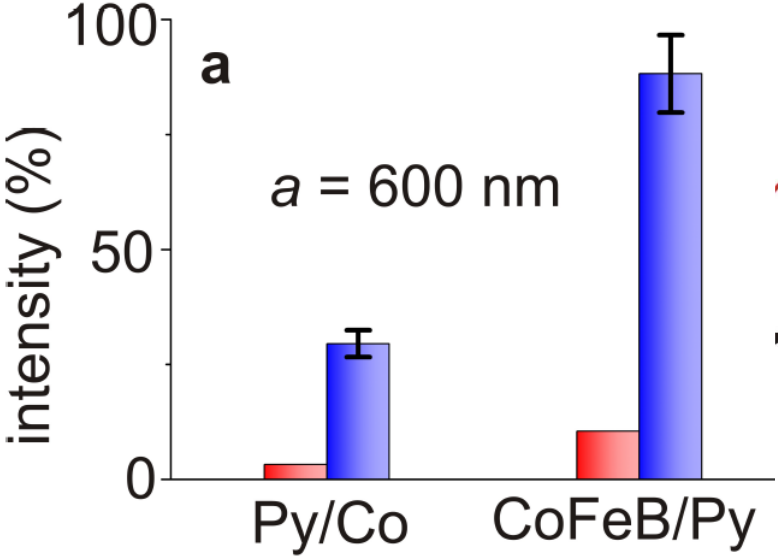


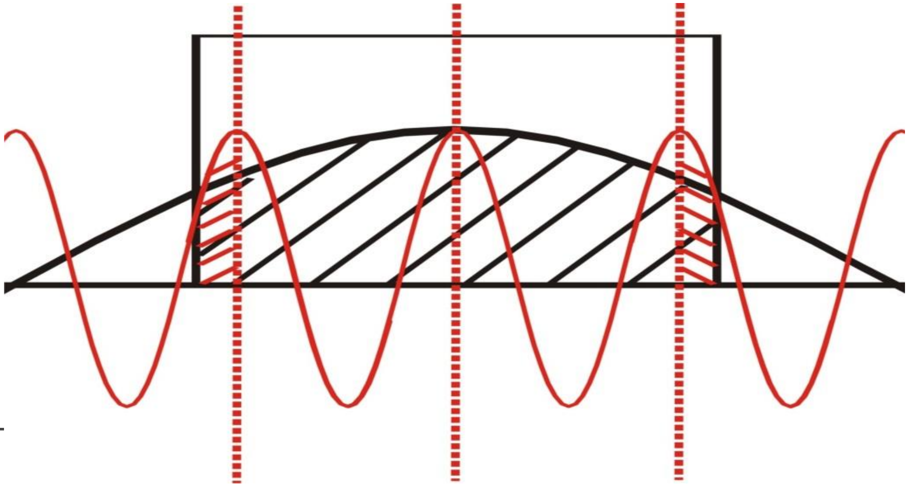
2D Bicomponent MCs (BMCs)

Magnonic Grating Coupler in MCs

Sample	t_1 nm	t_2 nm	t_3 nm	a nm	d nm	Filling fraction f'	Observed grating coupler modes	Maximum enhancement (%)
1D BMC (Py/CoFeB)	40	30	40	400	120	0.3	$k_I - G_{01}$	7183
2D BMC (Py/Co)	26	15	7	1000	430	0.15	$k_I - G_{01}$ $k_I - 2 \times G_{01}$ $k_I - 3 \times G_{01}$	1121
2D ADL	24	N/A	8	600	310	0.21	$k_I - G_{01}$ $k_I \pm G_{11}$ $k_I - G_{10}$	5931
2D BMC (CoFeB/Py)	48	25	15	800	420	0.22	$k_I \pm G_{01}$ $k_I \pm G_{11}$ $k_I \pm G_{10}$	20668

Material Dependence

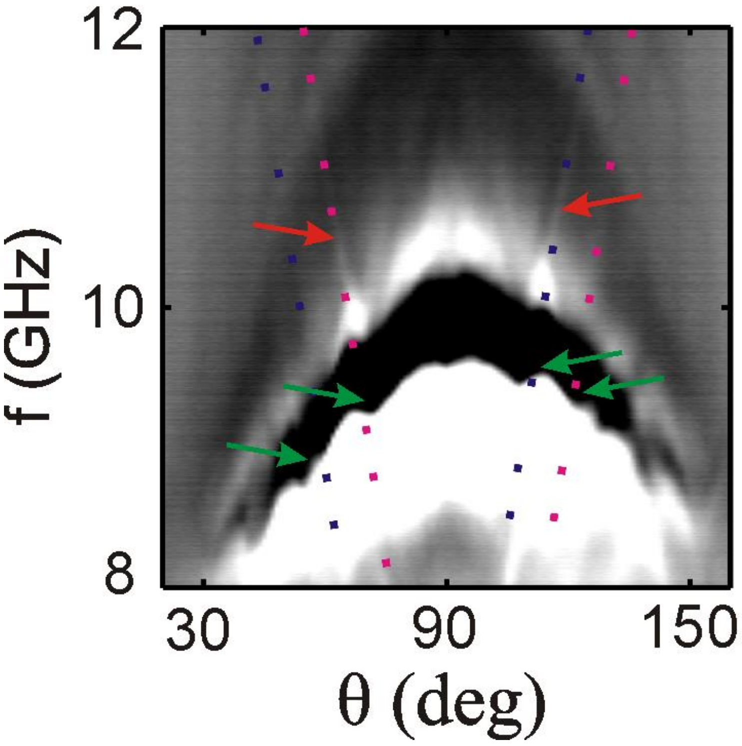




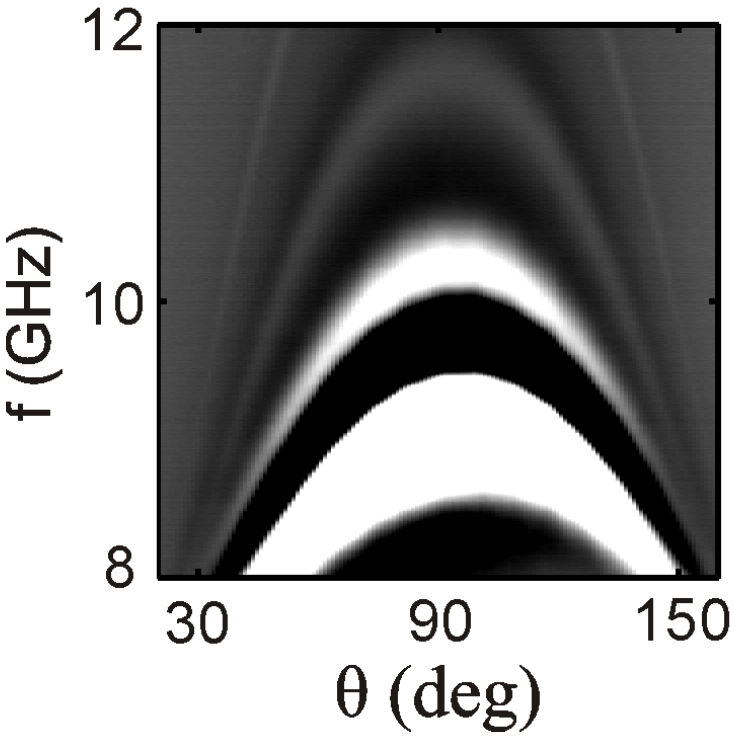
Transmission

$$\boxed{\vec{k}_{\mathrm{I}} - \vec{G}_{01} \quad \vec{k}_{\mathrm{I}} + \vec{G}_{01}}$$

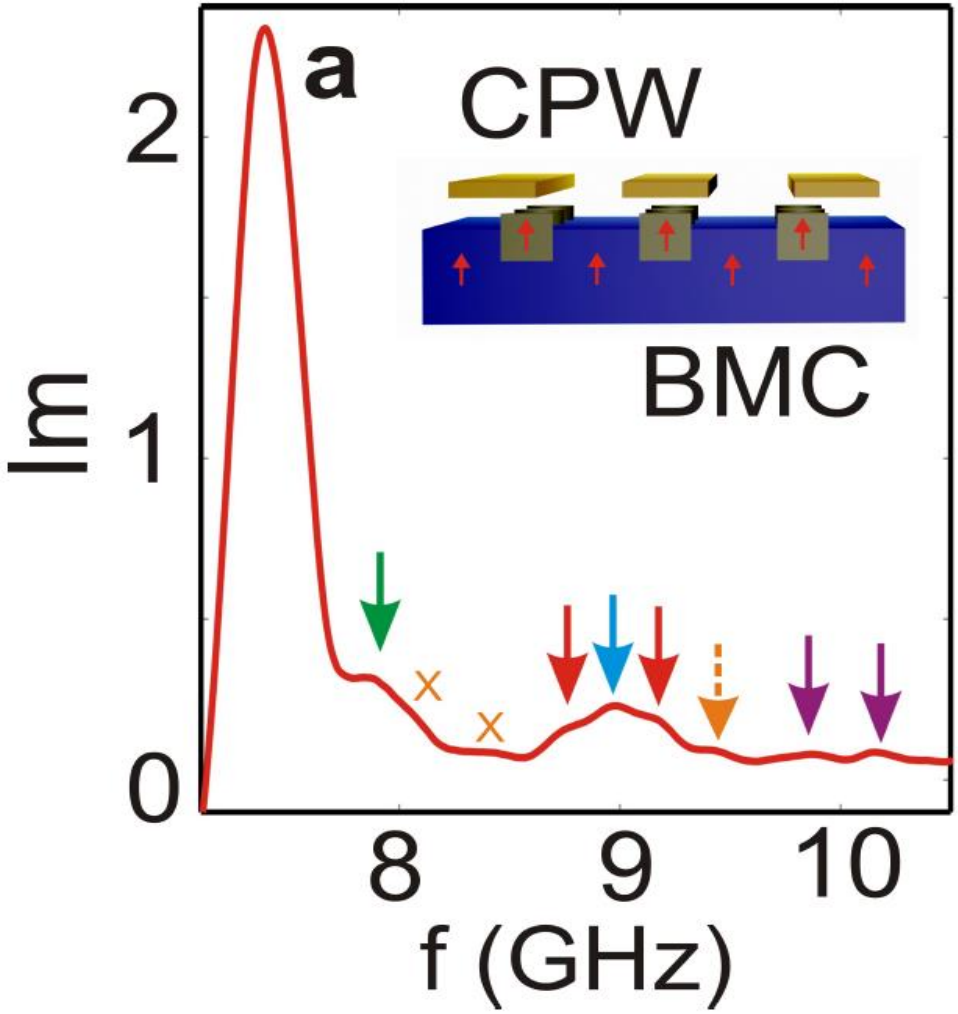
BMC S34



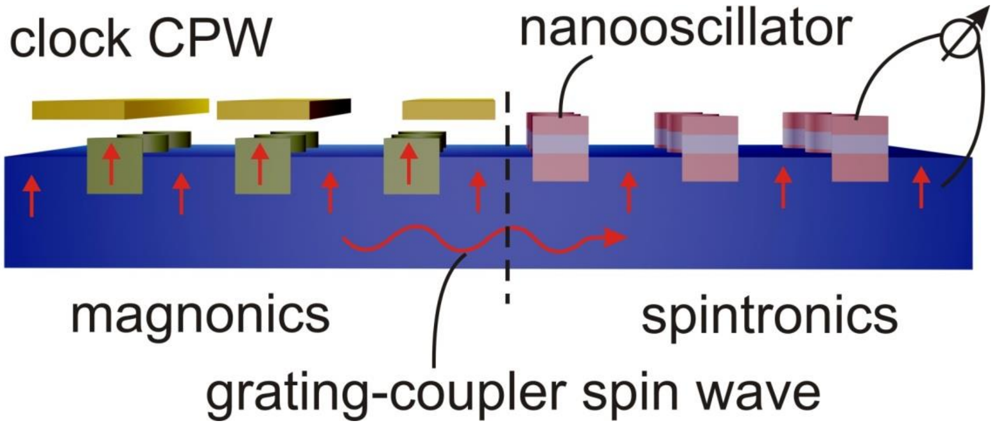
Plane film S12

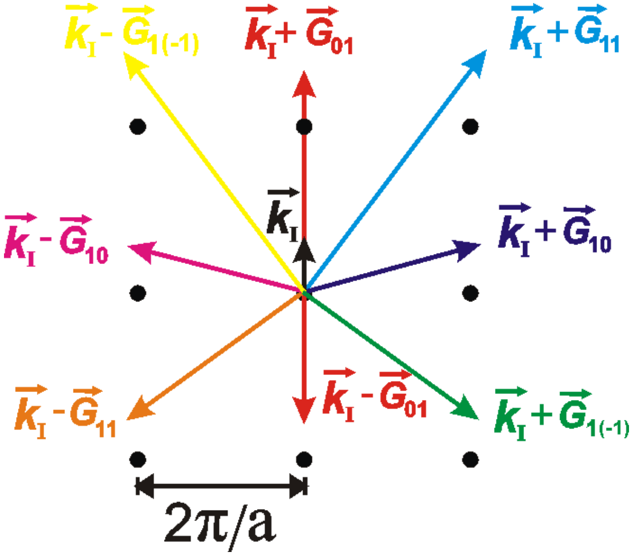


Out-of-plane Field @1.8T



Proposed Magnonic Device





Pufall, M. R. Rippard, W. H. Russek, S. E. Kaka, S. & Katine, J. A.
Electrical measurement of spin-wave interactions of proximate spin transfer nanooscillators.
Phys. Rev. Lett. **97**, 087206 (2006).